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Apple and Peach Orchard Establishment Following Multi-year Use of Diuron, Simazine, and Terbacil

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Abstract. **Combinations of diuron, simazine, and terbacil were applied every year over 15 and 16 years to the same plots. Apple (*Malus ×domestica* Borkh.) and peach (*Prunus persica* L.) trees then were planted 1 and 2 years following the last herbicide application. In general, apple-tree growth was not affected, but peach tree growth was reduced by some herbicide treatments. Peach-tree growth was reduced in plots treated with terbacil and soil organic matter was lowest in these plots. Time of last herbicide treatment did not affect apple- or peach-tree growth. The results indicated that reduced fruit-tree growth was associated with reduced soil organic matter and that residual terbacil may have inhibited peach-tree growth. Chemical names used: *N′*-(3,4-dichlorphenyl)-*N,N*-dimethylurea (diuron); 6-chloro-*N,N′*-diethyl-1,3,5-triazine-2,4-diamine (simazine); 5-chloro-3-(1,1-dimethylethyl)-6-methyl-2,4(1*H*,3*H*)-pyrimidinedione (terbacil).**

Diuron, simazine, and terbacil, have been available for nearly 30 years and have been applied repeatedly for weed control in fruit orchards in widely different environments. These herbicides can persist in soil for more than 1 year in quantities sufficient to cause damage to plants (Marriage et al., 1975). Occasionally, residues of diuron, simazine, or terbacil were found lower than 15 cm below the soil surface (Gomez de Barreda et al., 1996; Marriage et al., 1975, Tworkoski et al., 2000a). Fruit-tree roots could be exposed to herbicide residues at these depths. Fruit growers in the Appalachian region of the eastern United States may use diuron, simazine, and terbacil alone or in combination, and occasional failures of new fruit tree plantings have been attributed to herbicide residues. However, no information is available on the effect of past long-term use of these herbicides on future apple and peach plantings.

Repeat annual applications of diuron, simazine, or terbacil can cause residues to persist, but not accumulate in soil (Khan and Marriage, 1979; Skroch et al., 1971; Tworkoski et al., 2000a). Several experiments demonstrated that herbicide residues had little effect on peach and apple trees (Foy et al., 1996; Heeney et al., 1981). However, toxicity can vary with residue availability, which depends on soil conditions such as soil texture and percent organic matter (Day et al., 1968; Grover, 1966; Majek and Welker, 1990; Scribner et al., 1992; Upchurch and Mason, 1962). Herbicide residues may bind to humic materials in soil, and slow release of soil-bound residues may injure plants (Capriel et al., 1985). Herbicide-residue toxicity also varies with residue persistence which, in turn, depends on environmental conditions such as precipitation and herbicide incorporation (Skroch, 1970; Skroch et al., 1971; Weldon and Timmons, 1961). Thus, toxicity of residues from herbicide applications in prior years will depend on weed-management techniques that were used, climate, and edaphic conditions.

In mature fruit orchards, weeds are controlled to reduce competition, improve access to trees, and eliminate habitat of crop-damaging pests. Several experiments demonstrated that herbicides applied to soil can affect peach- and apple-tree growth. During the season of application, high rates of diuron, simazine, or terbacil reduced vigor and yield of young apple trees (Hogue and Neilsen, 1988). High rates of these same herbicides also reduced growth of peach trees, but trees recovered (Majek and Welker, 1990). The objective of this experiment was to determine the effects of past long-term use of different herbicides, applied at different rates and combinations on survival and growth of young apple and peach trees.

Materials and Methods

The experiment was conducted at the Appalachian Fruit Research Station in Jefferson County, W.Va., on Hagerstown silt loam (fine, mixed, mesic Typic Hapludalf). A randomized complete-block design with four replications was used. Twelve herbicide treatments were assigned to plots (2 × 10 m) that were selected randomly in each block composed of two rows. A 2-m grass strip separated each treated row. The herbicide treatments were applied to the same plots in May from 1981 through 1995. Prior to 1981, corn was grown on the site. Herbicide treatments were diuron, simazine, and terbacil applied alone or tank mixed in combinations of two herbicides at rates of 0, 2, or 4 $kg\cdot ha^{-1}$. In May 1996, each plot was divided into two subplots (2 × 5 m). One subplot received the last herbicide treatment in Spring 1996 while the other subplot was not treated in 1996. Soil was not disturbed on herbicide-treated plots. No crop was planted in any plot from 1981 to 1995. All plots were mowed to 20-cm height each February to remove tall shoots and to ensure uniform application of herbicides in May.

On 24 Apr. 1997, one peach tree ('Redhaven' on Lovell rootstock) and one apple tree ('Ace Spur Red Delicious' on M.7 rootstock) were shovel-planted in each subplot. No special precautions were used to avoid mixing soil. All plots were spot treated with glyphosate [*N*-(phosphonomethyl)-glycine] each month during the 1997 and 1998 growing seasons to eliminate weed competition and allow evaluation of the effects of continuous residual herbicide application over the previous 15 years. Weed abundance was evaluated visually as the percentage of area covered in a subplot each month during the 1997 growing season prior to glyphosate spot treatment. During 1997, total length of the current season growth from three branches per tree was measured each month. Tree diameter was measured at the beginning and end of the 1997 growing season. During 1998, season-long growth of trunk diameter and total length of three branches per tree were measured. Trunk diameter was measured 10 cm above the graft union. No trees died in any plot.

At the end of the 1997 growing season, soil bulk density and organic matter were measured. Three soil samples (5 cm diameter × 10 cm deep) were collected from each subplot, dried at 100 °C for 2 d, and weighed to determine bulk density. Samples were evaluated for organic carbon based on loss of carbon on ignition (Davies, 1974).

Apple and peach tree data were evaluated as separate experiments. Each experiment was a randomized complete-block design with a split-plot arrangement. Herbicide treatment was a whole plot and time of last weed-control treatment was the split plot. There were 12 herbicide treatments evaluated with diuron as one main effect (0, 2, and 4 $kg\cdot ha^{-1}$), simazine/terbacil as a second main effect (simazine at 0, 2, and 4 $kg\cdot ha^{-1}$ and terbacil at 2 $kg\cdot ha^{-1}$), and time of last herbicide treatment as a third main effect (1995 and 1996). Experimental units were single trees, four replications were used, and a total of 96 trees per species were planted. Herbicide, time of last treatment, and interactions were analyzed by analysis of variance. Linear and quadratic trends of growth responses to simazine rates were analyzed with orthogonal polynomial contrasts and growth responses to terbacil were analyzed with planned contrasts. Pearson correlation was used to analyze relationships between soil properties and fruit-tree growth.

Results and Discussion

Repeated annual herbicide treatments over 15 years had little impact on growth of newly planted apple trees (data not shown). Year of

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final herbicide treatment also did not affect trunk growth or shoot growth of apple trees in 1997 or 1998. Skroch et al. (1975) observed reduced apple shoot elongation in plots with soil residues of simazine and terbacil. However, trunk diameter was greatest in plots that received herbicide treatment. The reduced shoot elongation was attributed to greater fruit loads on apple trees in sites treated with simazine and terbacil. Based on a bioassay, Foy et al. (1996) demonstrated that tree growth would not be affected by herbicide residue, particularly when tree roots grew below 7.5 cm. Our results corroborate those of Skroch et al. (1975) and Foy et al. (1996) that herbicide residues, even after long-term use, do not adversely affect growth of young apple trees.

Unlike apple trees, herbicide use affected the growth of peach trees during 1997 and 1998 (Table 1). Reduced growth was consistently associated with terbacil-treated plots. Increased simazine concentration without terbacil caused a small, but linear decrease in peach trunk diameter and shoot growth during 1998 (Table 1). Shoot growth was at least 45% greater in peach than apple trees. We have observed more root growth in newly planted peach than apple trees. It is possible that, in this experiment, peach trees may have absorbed herbicide residues or encountered edaphic limitations that apple trees did not. As with apples, year of final herbicide application did not affect growth of peach trees.

Previous experiments demonstrated that with specified conditions, herbicide residues could inhibit fruit-tree growth. When applied above the recommended rates, diuron, simazine, and terbacil caused reduced vigor and yield (Hogue and Neilson, 1988). At recommended rates, no injury was observed. In another study, Majek and Welker (1990) found that heavy rainfall, where trees were planted with mounding, could increase the concentration of terbacil in the root zone and cause chlorosis in peach leaves. In the current study, the concern was that many years of application of the same herbicide could increase herbicide concentration by residue carryover and injure a new planting of fruit trees. No evidence of a carryover effect was found for diuron. Terbacil-treatments reduced shoot growth during both years and trunk diameter growth during 1998 in peach (Table 1). An assay of the soil in this experiment demonstrated that 25% terbacil carryover occurred from one annual application to the next, but terbacil did not build up in soil (Tworkoski et al., 2000a). However, terbacil residues were found to 60 cm soil depth.

Soil organic matter and bulk density were analyzed, because previous studies of weed community changes demonstrated low vegetation abundance on some plots that received long-term herbicide treatments (Tworkoski et al., 2000b). It was hypothesized that reduced vegetation over many years could lead to decreased soil organic matter or to increased bulk density. In the current experiment, organic matter differed due to weed-control treatment, but bulk density did not (Table 2, data not shown). Lowest organic matter was found in plots receiving terbacil. Terbacil-treated plots also had the least weed growth (Tworkoski et al., 2000b). It is possible that reduced peach-tree growth was associated with reduced organic matter and not with terbacil residues. Organic matter aerates soil and provides surfaces for ion exchange. Thus, reduced organic matter from repeated previous use of terbacil likely will adversely affect tree growth due to reduction in edaphic resources. In this experiment, organic matter was correlated significantly with shoot growth in peach but not apple trees ($r = 0.50$, $P = 0.01$ and $r = 0.14$, $P = 0.25$, respectively, n = 72). However, organic matter also adsorbs herbicides and renders them less toxic. Thus, reduced organic matter associated with reduced weed growth in terbacil-treated plots may have increased terbacil availability for peach tree uptake.

In this experiment, weed abundance was evaluated as a bioassay to compare with tree growth. Herbicide treatment had a limited impact on weed abundance (Table 2). Weed abundance was reduced in September by simazine/terbacil treatments. The only significant effect of year of final weed-control treatment occurred with weed abundance measured in June 1997 (Table 2). Greater weed abundance was found in subplots last treated in 1995 than subplots last treated in 1996. Herbicide residue carryover occurs in the year following application, and these residues may have inhibited growth of early-season weeds (Tworkoski et al., 2000a). With increased time during the 1997 growing season, year of final treatment was not significant, suggesting that

Table 1. Effects of 15 years of herbicide treatments and year of last treatment on growth of newly planted 'Redhaven' peach trees on Lovell rootstock.

		Trunk diam (mm)		Shoot length (cm)	
Main effect					
	0				
	2				
	4				
Simazine/Terbacil (kg·ha^{-1})	Simazine 0				
	Simazine 2				
	Simazine 4				
	Terbacil 2				
Year of last herbicide application	1995				
	1996				
Source of variation	df				
Diuron (D)	2	0.38			
Simazine/Terbacil (S/T)	3	0.15			
Year of last herbicide application (Y	1	0.70			
D × S/T	6	0.02			
D × Y	2	0.82			
S/T × Y	3	0.09			
D × S/T × Y	6	0.52			
Contrast					
Simazine Linear		0.23	0.03	0.75	0.04
Quadratic		0.62	0.36	0.87	0.96
Terbacil vs. Simazine		0.06	0.01	0.01	0.01

Table 2. Effects of 15 years of herbicide treatments and year of last treatment on soil organic matter and weed abundance in 1997.

Main effect		Organic matter	Weed abundance June[z]	July	Aug.	Sept.
		(%)				
Diuron (kg·ha^{-1}	0	2.8				
	2	2.7				
	4	2.5				
Simazine/Terbacil (kg·ha^{-1})	Simazine 0	3.1				
	Simazine 2	2.8				
	Simazine 4	2.8				
	Terbacil 2	2.0				
Year of last herbicide application	1995	2.7				
	1996	2.6				
Source of variation	df					
Diuron (D)	2	0.41				
Simazine/Terbacil (S/T)	3	0.01				
Year of last herbicide application (Y)		0.42				
D × S/T	6	0.94				
D × Y	2	0.23				
S/T × Y	3	0.84				
D × S/T × Y	6	0.91				
Contrast						
Simazine Linear		0.24	0.69	0.91	0.86	0.87
Quadratic		0.53	0.43	0.81	0.82	0.09
Terbacil vs. Simazine		0.01	0.96	0.38	0.39	0.01

[z]Measured in June 1997 prior to the first spot application of glyphosate.

herbicide residues, if present, were not biologically effective against weeds. These data may indicate that terbacil residues were active against weeds and peach-tree growth. However, long-term terbacil applications may have reduced the number of weed seed in soil so that the number of emergent seedlings rather than seedling mortality led to reduced weed cover.

This experiment demonstrated that long-term weed-control treatments can influence growth of peach trees. Terbacil treatments reduced peach tree growth, but soil organic matter also was reduced. It is possible that, due to their fast growth, peach trees reflected effects of edaphic constraints. Soil organic matter was low in plots with reduced peach-tree growth. Previous work indicated that soil microflora populations were reduced on sites with reduced vegetation from herbicide treatments due to reduced organic matter (Tworkoski and Welker, 1996). It is possible that poor soil aeration, fertility, or microflora activity were responsible for reduced peach-tree growth on plots that were maintained vegetation-free by terbacil for 15 years. The results from this study suggest that site preparation for peach-tree planting could benefit from improved organic matter when reduced by previous use of herbicides. Herbicide residues from prior long-term applications of diuron and simazine, at 2 and 4 $kg \cdot ha^{-1}$, had little or no effect on growth of newly planted apple and peach trees. However, long-term use of terbacil can adversely affect growth of newly-planted peach trees.

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